Future Measurements of Transversity[1]

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Abstract: A review of envisaged future quark transversity measurements is presented.

1 Introduction

A quark of a given flavor in the nucleon is characterized by three twist-two quark distributions: the number density distribution $q(x)$, the helicity distribution $\Delta q(x)$, and the experimentally unknown transversity distribution $\delta q(x)$, which characterizes the distribution of the quark's transverse spin in a transversely polarized nucleon. For non-relativistic quarks $\delta q(x) = \Delta q(x)$ can be expected, but generally both distribution functions are independent. Soffer's inequality for each quark flavor, $2|\delta q(x, Q^2)| \leq q(x, Q^2) + \Delta q(x, Q^2)$, restricts possible values of the transversity distributions.

The transversity distribution was first discussed by Ralston and Soper [1] in doubly transverse polarized Drell-Yan (DY) scattering. Its measurement is one of the main goals of the spin program at RHIC. The transversity distributions $\delta q(x)$ are not accessible in inclusive DIS, because they are chiral-odd and only occur in combinations with other chiral-odd objects. In semi-inclusive DIS of unpolarized leptons off transversely polarized nucleons several methods have been proposed to access $\delta q(x)$ via specific single target-spin asymmetries.

2 Measurement of $\delta q(x)$ in pp Collisions

An evaluation of the DY asymmetry $A_{TT} \sim \sum e_i^2 \delta q_i(x) \delta \bar{q}_i(x)$ was carried out [2] by assuming the saturation of Soffer's inequality for the transversity distributions. The maximum possible asymmetry at RHIC energies was estimated to be $A_{TT} = 1 \div 2\%$ (see fig.1a). At smaller energies, e.g. for a possible fixed-target experiment HERA-$\vec{N}$ [3] ($\sqrt{s} \simeq 40$ GeV), the asymmetry is expected to be higher.

A better sensitivity to $\delta q(x)$ is expected in a measurement of two-meson correlations with the nucleon's transverse spin. The interference effect between the s- and p-waves of the two-meson system allows the quark's polarization information to be carried through $\vec{k}_+ \times \vec{k}_- \cdot \vec{S}_\perp$ [4, 5]. Here, $\vec{k}_+$ and $\vec{k}_-$ are the meson momenta, and $\vec{S}_\perp$ is the proton spin vector. The corresponding asymmetry depends on the unknown chiral-odd interference quark fragmentation function (FF), $\delta \hat{q}_I(z)$. The function $\delta \hat{q}_I(z)$ has a theoretical upper bound and could be measured in $e^+ e^- \to (\pi^+ \pi^- X)(\pi^+ \pi^- X)$. To estimate a possible level of the asymmetry at RHIC energies two assumptions were made [5]: i) $\delta q(x, Q^2)$ saturates Soffer's inequality, and ii) $\delta \hat{q}_I(z)$ saturates its upper bound. This approach produces the *maximally possible* asymmetry. The projections of the asymmetry measurement with PHENIX at RHIC [6] are shown in fig. 1b.

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[1]Talk presented by V.A. Korotkov at the International Workshop "Symmetries and Spin, Praha-Spin-2000", Prague, July 17-22, 2000
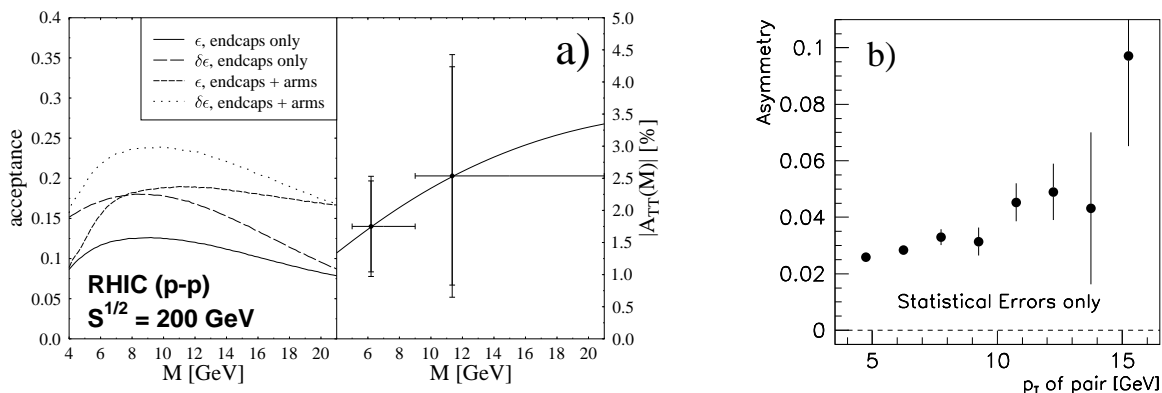
Figure 1: *Projections for measurements with PHENIX ($\sqrt{s} = 200$ GeV) of a) Drell-Yan asymmetry A_{TT} (L = 320 pb^{-1}) [2], and b) two-pion asymmetry (L = 32 pb^{-1}) [6].*

3 Measurements of $\delta q(x)$ in SIDIS

In semi-inclusive deep inelastic lepton scattering (SIDIS) off transversely polarized nucleons there exist several methods to access transversity distributions. One of them, namely twist-3 pion production [7], uses longitudinally polarized leptons and a double spin asymmetry is measured. The other methods do not require a polarized beam, they rely on polarimetry of the scattered transversely polarized quark: i) measurement of the transverse polarization of Λ's in the current fragmentation region [8]; ii) observation of a correlation between the nucleon's transverse spin vector and the normal to the two-meson plane [4]; iii) observation of the Collins effect in quark fragmentation through the measurement of pion single target-spin asymmetries [9]. HERMES data [10] indicate that the polarized FF $H_1^{\perp q}(z)$, responsible for the Collins effect, is quite sizeable.

3.1 Future Measurements at HERMES

The expected statistics for running at HERMES ($E = 27.5$ GeV) with a transversely polarized proton target will consist of about seven millions reconstructed DIS events. As average beam and target polarizations $P_B = 50\%$ and $P_T = 75\%$, respectively, are used for the analysis. DIS events are defined as those satisfying the following set of kinematic cuts: $Q^2 > 1$ GeV^2, $W > 2$ GeV, $0.02 < x < 0.7$, $y < 0.85$. The following cuts were assumed for the kinematic variables of the pion: $x_F > 0.$, $z > 0.1$, $P_{h\perp} > 0.05$ GeV.
The approximation $\delta q(x) = \Delta q(x)$ could be used for the evaluation of the below given projections in view of the relatively low Q^2-values at HERMES.

Twist-3 Pion Production. An effect of the transversity distributions in the spin-dependent cross-section of pion production in DIS of longitudinally polarized leptons on a transversely polarized nucleon target can appear only at the twist-3 level, when $\delta q(x)$ contributes through coupling with the chiral-odd twist-3 FF $\hat{e}(z)$ [7]. A simple relation between $\hat{e}(z)$ and the unpolarized FF $D(z)$ has been predicted in the chiral quark model [11] $\hat{e}(z) = zD(z)\frac{m_q}{M} \approx \frac{1}{3}zD(z)$, where m_q is the constituent quark mass. In the particular case of forming the asymmetry for
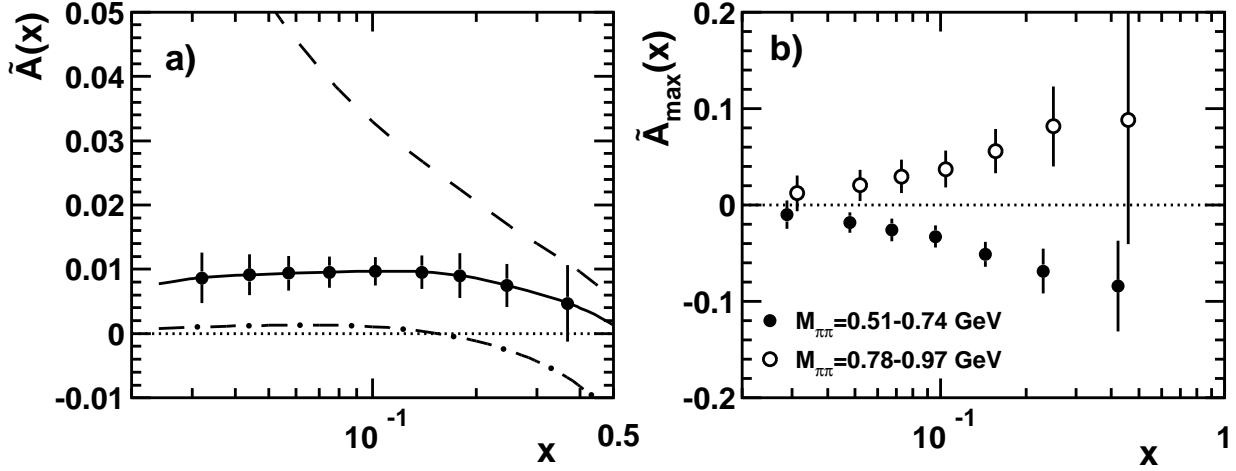
Figure 2: *Projections for a measurement at HERMES of a) twist-3 asymmetry for $\pi^+ + \pi^-$ production (dash-dotted curve — $\delta q(x) = 0$, dashed curve — saturation of the Soffer's inequality, solid curve — $\delta q(x) = \Delta q(x)$), b) two-pion asymmetry.*

the sum of π^+ and π^- production on a proton target:

$$A(x, y, \phi) = \cos\phi \cdot \frac{2Mx}{\sqrt{Q^2}} \cdot \frac{2y\sqrt{1-y}}{1 + (1-y)^2} \cdot \frac{g_T(x) + h_1(x)/3x - (1 - y/2)g_1(x)}{F_1(x)}, \qquad (1)$$

where $h_1(x) = \frac{1}{2}\sum_i e_i^2 \delta q_i(x)$, $g_T(x) = g_1(x) + g_2(x)$, and ϕ is the azimuthal angle between the lepton scattering plane and the spin plane. The projections for a measurement of this twist-3 pion asymmetry at HERMES are shown in fig. 2a, where the asymmetry $\tilde{A}(x, y) = P_B \cdot P_T \cdot A(x, y, \phi)/\cos\phi$ is shown for convenience.

Two-Meson Correlations with Transverse Spin. As has been noted above, the asymmetry in this case depends on the unknown chiral-odd interference quark FF $\delta\hat{q}_I(z)$, $\mathcal{A}_{\perp T} \sim \sum_a e_a^2 \delta q_a(x)\, \delta\hat{q}_I^a(z)$.

A *maximally* possible asymmetry with respect to the interference FF can be obtained with its upper bound. For $\pi^+\pi^-$ pair production at a proton target the maximal asymmetry takes the form:

$$A_{max} = -\frac{\pi}{\sqrt{32}} \cos\phi \, \sin(\delta_0 - \delta_1) \, D_{nn} \frac{\delta u_v(x) - \frac{1}{4}\delta d_v(x)}{(u(x) + \bar{u}(x)) + \frac{1}{4}(d(x) + \bar{d}(x))}, \qquad (2)$$

where $\cos\phi = \vec{k}_+ \times \vec{k}_- \cdot \vec{S}_\perp / |\vec{k}_+ \times \vec{k}_-||\vec{S}_\perp|$; D_{nn} is the transverse polarization transfer coefficient, and $\delta_{0,1} = \delta_{0,1}(m^2)$ are strong interaction $\pi\pi$ phase shifts. The asymmetry has been calculated in two regions of the two-pion mass to avoid averaging to zero due to the factor $\sin(\delta_0 - \delta_1)$. The projections for its measurement at HERMES are shown in fig. 2b in terms of $\tilde{A}_{max} = P_T \cdot A_{max}/\cos\phi$.

Collins effect. In the case of an unpolarized beam and a transversely polarized target the following *weighted asymmetry* [12] provides access to the quark transversity distribution via the Collins effect:

$$A_T(x,y,z) \equiv \frac{\int d\phi^\ell \int d^2 P_{h\perp} \frac{|P_{h\perp}|}{zM_h} \sin(\phi_s^\ell + \phi_h^\ell) \left(d\sigma^\uparrow - d\sigma^\downarrow\right)}{\int d\phi^\ell \int d^2 P_{h\perp}(d\sigma^\uparrow + d\sigma^\downarrow)}, \tag{3}$$

where $P_{h\perp}$ is the pion's transverse momentum and the azimuthal angles are defined in the transverse space giving the orientation of the lepton plane (ϕ^ℓ) and the orientation of the hadron plane ($\phi_h^\ell = \phi_h - \phi^\ell$) or spin vector ($\phi_s^\ell = \phi_s - \phi^\ell$) with respect to the lepton plane. The asymmetry (3) can be estimated from

$$A_T(x,y,z) = P_T \cdot D_{nn} \cdot \frac{\sum_q e_q^2 \, \delta q(x) \, H_1^{\perp(1)q}(z)}{\sum_q e_q^2 \, q(x) \, D_1^q(z)}. \tag{4}$$

The assumption of u-quark dominance was used to calculate the expected asymmetry $A_T^{\pi^+}(x)$ [14]. In this case the asymmetry for a proton target reduces to

$$A_T^{\pi^+}(x,y,z) = P_T \cdot D_{nn} \cdot \frac{\delta u(x)}{u(x)} \cdot \frac{H_1^{\perp(1)u}(z)}{D_1^u(z)} \tag{5}$$

The approach of Ref. [12] is adopted to estimate $H_1^{\perp(1)u}(z)/D_1^u(z)$.

The factorized form of expression (5) with respect to x and z allows the simultaneous reconstruction of the shape for both unknown functions $\delta u(x)$ and $H_1^{\perp(1)u}(z)/D_1^u(z)$ if measurements of the asymmetry are done in (x,z) bins, while the relative normalization cannot be fixed without a further assumption. The differences between $\delta q(x)$ and $\Delta q(x)$ are smallest in the region of intermediate and large values of x [14]. Hence the assumption $\delta q(x_0) = \Delta q(x_0)$ at $x_0 = 0.25$ was made to resolve the normalization ambiguity. The projections for a measurement of $A_T^{\pi^+}(x)$, $\delta u(x)$, and $H_1^{\perp(1)u}(z)/D_1^u(z)$ at HERMES are shown in fig. 3.
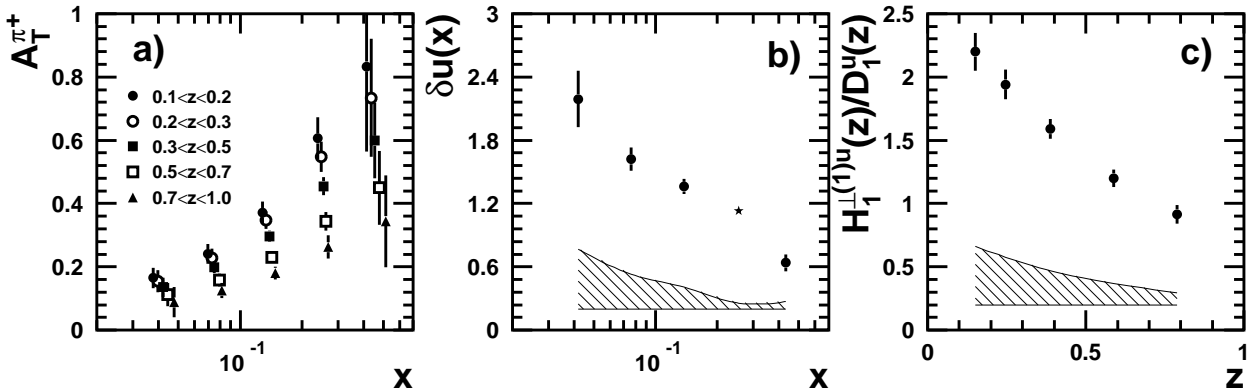

Figure 3: *a) The weighted asymmetry $A_T^{\pi^+}(x)$ in different intervals of z; b) the transversity distribution $\delta u(x)$, and c) the ratio of the fragmentation functions $H_1^{\perp(1)u}(z)/D_1^u(z)$ as it would be measured by HERMES. The asterisk in b) shows the normalization point. The hatched bands in b) and c) show projected systematic uncertainties due to the normalization and the u-quark dominance assumptions.*

3.2 The Experiment TESLA-N

The basic TESLA-N [13] idea is to use one of the arms of the presently planned e^+e^- collider TESLA at DESY to accomplish collisions of longitudinally polarized electrons ($E = 250$ GeV, $P_B = 90\%$) with a polarized solid-state fixed target. Presently, the target materials NH_3 ($P_T = 0.8$, f = 0.176) and ^{6}LiD ($P_T = 0.3$, f = 0.44) appear as the best choices to study electron scattering off polarized protons and deuterons, respectively.

The physics projections presented below are based on an integrated luminosity of 100 fb^{-1}. This represents a conservative estimate for *one* year of data taking.

Measurements of single target-spin asymmetries due to the Collins effect in the production of positive and negative pions on proton and deuteron targets ($A_{p,d}^{\pi^+,\pi^-}$) allow, under reasonable assumptions, the simultaneous reconstruction of the shapes of the unknown functions $\delta q(x, Q^2)$ and $H_1^{\perp(1)}(z)/D_1(z)$. Again the relative normalization cannot be fixed without an independent measurement or a further assumption. This ambiguity can be resolved by relating $\delta q(x)$ to $\Delta q(x)$ at small values of Q^2. Following ref. [14], the normalization ambiguity is resolved by assuming $\delta u(x_0, Q_0^2) = \Delta u(x_0, Q_0^2)$ at $x_0 = 0.25$.

The projections for the measurement of $\delta u_v(x, Q^2)$ at TESLA-N are shown in fig. 4. A broad range of $0.003 < x < 0.7$ can be accessed in conjunction with $1 < Q^2 < 100$ GeV^2. A simultaneous reconstruction of the quark transversity distributions δd_v, $\delta \bar{u}$, and $\delta \bar{d}$ is attained with a somewhat lower accuracy. Projections for the accuracies of a measurement of the u- and d-quark tensor charges are ± 0.01 and ± 0.02 at the scale of 1 GeV^2, respectively. At the same time, precise values would be measured for the ratio of polarized and unpolarized favored quark fragmentation functions $H_1^{\perp(1)}(z)/D_1(z)$, assumed to be flavor-independent in this analysis.
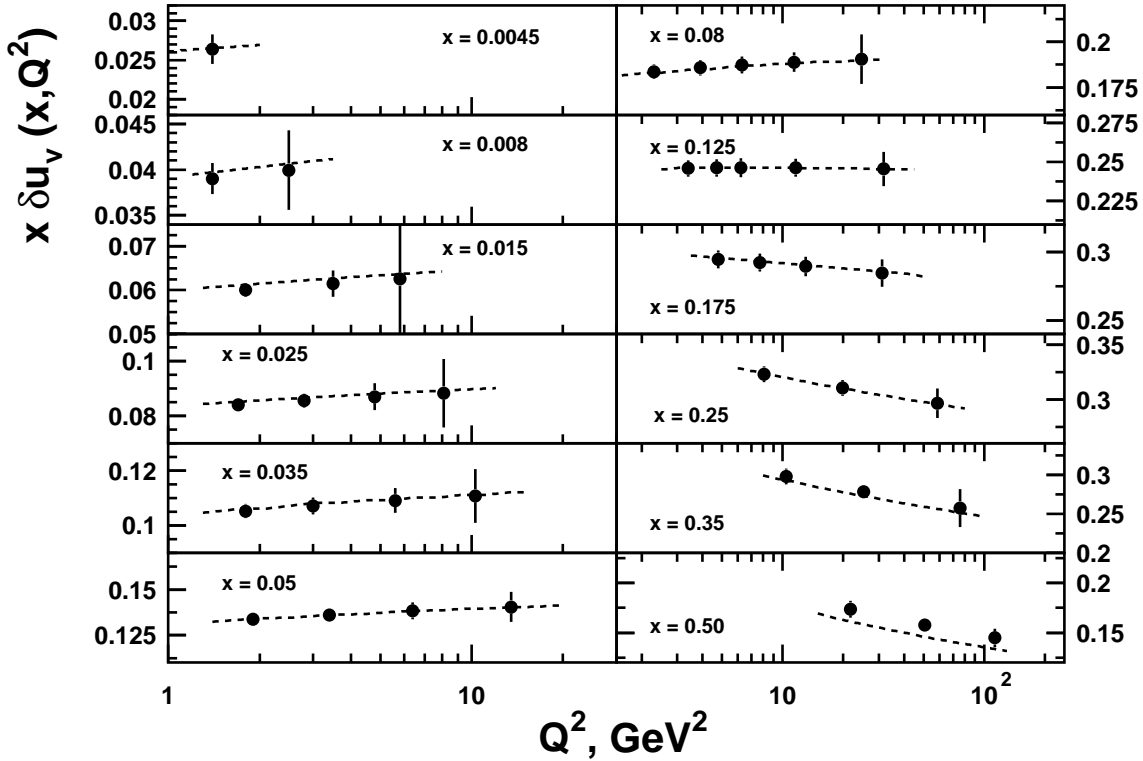

Figure 4: The transversity distribution $\delta u_v(x, Q^2)$ as it would be measured at TESLA-N. The curves show the LO Q^2-evolution of δu_v obtained with a fit to the simulated asymmetries.

4 Summary

A measurement of the transversity distributions in polarized proton-proton collisions at RHIC will be possible if the chiral-odd interference fragmentation function, $\delta\hat{q}_I$, is not heavily suppressed relative to its theoretical upper bound.

The HERMES experiment using a transversely polarized proton target will be capable in a few years to measure simultaneously and with good statistical precision the u-quark transversity distribution $\delta u(x)$ and the ratio of the fragmentation functions $H_1^{\perp(1)u}(z)/D_1^u(z)$.

A measurement of the quark transversity distributions as a function of x and Q^2 with good statistical accuracy requires a new high luminosity and high energy polarized lepton-nucleon experiment. The physics potential of the TESLA-N project is demonstrated by showing that an accurate measurement of the x- and Q^2-dependence of the transversity quark distributions would be possible.

References

[1] J. Ralston, D.E. Soper, Nucl. Phys. **B152** (1979) 109.

[2] O. Martin et al., Phys. Rev. **D60** (1999) 117502.

[3] V.A. Korotkov and W.-D. Nowak, Nucl. Phys. **A622** (1997) 78c.

[4] R.L. Jaffe, X. Jin, J. Tang, Phys. Rev. Lett. **80** (1998) 1166.

[5] J. Tang, MIT-CTP-2769, 1998, hep-ph/9807560.

[6] M. Grosse Perdekamp, *DIS-2000*, Liverpool, 25-30 April 2000;
    Workshop *Future Transversity Measurements*, BNL, 18-20 September 2000.

[7] R.L. Jaffe, X.J. Ji, Phys. Rev. Lett. **71** (1993) 2547.

[8] R.L. Jaffe, Phys. Rev. **D54** (1996) 6581.

[9] J.C. Collins, Nucl. Phys. **B396** (1993) 161;
    J.C. Collins, S.F. Heppelmann, G.A. Ladinsky, Nucl. Phys. **B420** (1994) 565.

[10] HERMES Coll., A. Airapetian et al., Phys. Rev. Lett. **84** (2000) 4047.

[11] X. Ji, Z.-K. Zhu, hep-ph/9402303, 1994.

[12] A.M. Kotzinian, P.J. Mulders, Phys.Lett. **B406** (1997) 373.

[13] http://www.ifh.de/hermes/future/ and F. Ellinghaus, these Proceedings.

[14] V.A. Korotkov, W.-D. Nowak, K.A. Oganessyan, DESY 99-176, hep-ph/0002268,
    subm. to EPJ C.